Chapter 5

Stratigraphy of Jurassic Sediments of the Southern Siberian Platform (Russia) Studied through Lithologic and Paleobotanical Data

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Abstract

This paper presents the results of comprehensive lithologic and paleobotanical study of Jurassic sediments of the Irkutsk Coal Basin revealed in outcrops and sections within operating coal deposits. The lithologic characteristics of the main stratigraphic units of the Irkutsk Basin: Cheremkhovskaya, Prisayanskaya, and Kudinskaya Formations are given. Two uneven-aged fossil plant assemblages: Cheremkhovo for middle and upper subformations of Cheremkhovskaya Formation and Prisayan for Prisayanskaya and Kudinskaya Formations have been identified. *Equisetites lateralis* (Phill.) Phill., *E. asiaticus* Pryn., *Cladophlebis haiburnensis* (L. et H.) Sew., *Sphenobaiera czekanowskiana* (Heer) Flor., *S. vigentis* Kiritch. et Bat., *Czekanowskia baikalica* Kiritch. et Samyl., and *Cz. rigida* Heer species are typical of the Cheremkhovo assemblage. The age of sediments including the Cheremkhovo assemblage is the end of Early Jurassic (conventionally, Toarcian). *Coniopteris maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *C. murrayana* (Brongn.) Brongn., *C. spectabilis* Brick., *Cladophlebis nebbensis* (Brongn.) Nath., *Raphaelia diamensis* Sew., *R. tapkensis* (Heer) Pryn. emend Kost., *Phoenicopsis angustifolia* Heer, *Ph. cognata* Kiritch., and *Ph. irkutensis* Dolud. et Rasskaz species are characteristic of the Prisayan assemblage. Prisayan assemblage sediments are dated at the beginning of Middle Jurassic (conventionally, Aalenian). The stratigraphic correlation of Jurassic sediments of the Irkutsk Coal Basin with the sedimentary basins of Western Siberia has been carried out based on paleobotanical data.

Keywords: Jurassic sediments, stratigraphy, fossil and flora assemblages, Irkutsk Basin, Siberian platform

1. Introduction

Lower and middle Jurassic continental sediments of Siberia are abundant. They are exposed along river valleys and gorges, within quarries and mine workings of the Kuznetsk, Kansk, Irkutsk, and other Coal Basins. Lower and Middle Jurassic sediments are rich in plant remains, which are important in stratigraphy and correlation of continental complex of Jurassic sediments where large coal deposits are concentrated. The Irkutsk Basin situated within the southern Siberian platform is one of them (**Figure 1**). Three structural and facies zones: Prisayan piedmont trough, Platform limb, and Angara-Koty intermountain area are clearly distinguished within it [2]. According to the regional stratigraphic scheme, the Jurassic sediments of the Platform limb and Prisayan piedmont trough are subdivided into three formations: Cheremkhovskaya, Prisayanskaya, and Kudinskaya. Cheremkhovskaya Formation

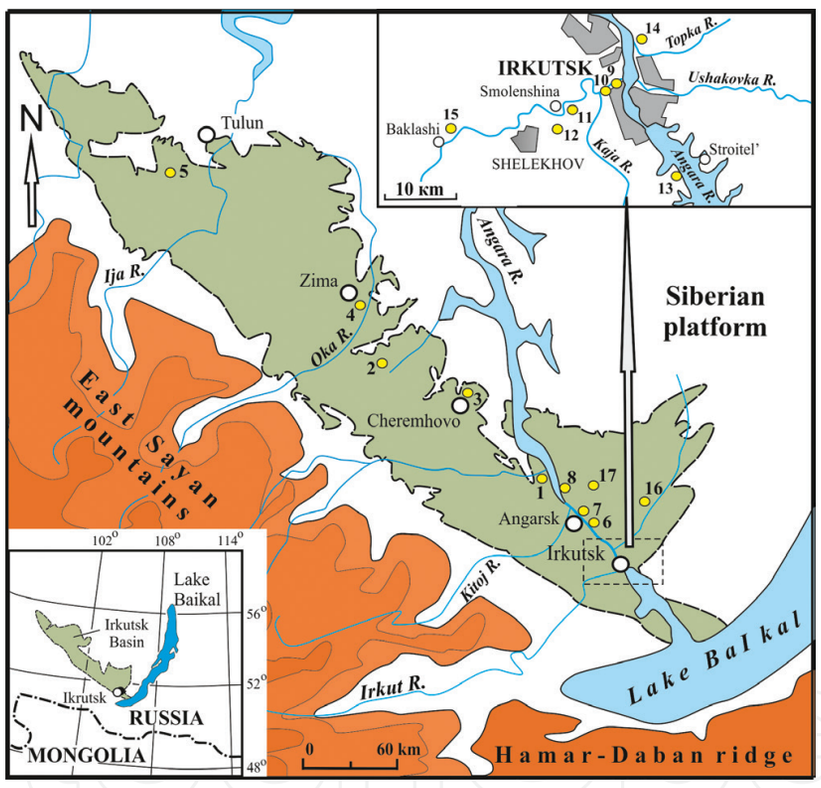

Figure 1. Layout of the studied key sections. 1—the left bank of the Bol'shaya Belaya river at 200 m below the railway bridge in the Taiturka settlement (GPS: N52°86.242′; E103°49.371′); 2—the right bank of the Zalari river, on the opposite side of the Zalari settlement (GPS: N53°55.924′; E102°55.199′); 3—the Cheremkhovo coal deposit (GPS: N53°20.329′; E103°11.985′); 4—the Glinki coal deposit (GPS: N53°86.684′; E102°26.406′); 5—the Mugun coal deposit (GPS: N54°43.050′; E100°18.245′); 6—the right bank of the Angara river, the Ust'-Balei creek (GPS: N52°62.771′; E103°96.128′); 7—the right bank of the Angara river, the Tolstyi Cape (GPS: N52°63.714′; E103°93.978′); 8—the right bank of the Angara river, on the opposite side of the Tel'ma settlement (GPS: N52°70.676′; E103°77.649′); 9—the right bank of the Irkut river, Kaiskaya Gora (GPS: N52°28.331′; E104°23.019′); 10—Sinyushina Gora (GPS: N52°15.888′; E104°11.188′); 11—the Olkha river, the Smolenshchina settlement (GPS: N52°15.006′; E104°9.305′); 12—the Olkha river, Olkhinskaya Gora area; 13—the left bank of the Irkutsk water reservoir, on the opposite side of the Stroitel' dacha (GPS: N52°11.195′; E104°23.459′); 14—the right bank of the Angara river, the Topka creek valley (GPS: N52°21.289′; E104°17.282′); 15—the left bank of the Irkut river, at 2 km above the Pionersk settlement (GPS: N52°23.734′; E103°99.541′); 16—the right bank of the Kuda river, 2 km to the north of the Zherdovka settlement (GPS: N52°66.490′; E104°57.222′).

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is composed of three subformations: lower, middle, and upper and Prisayanskaya includes lower and upper subformations. The stratigraphic sequences of these formations and their lithologic characteristics were confirmed by lithostratigraphic data in different boreholes and natural sections [1, 28].

Since the second half of the nineteenth century, the Early-Middle Jurassic flora of the Irkutsk Basin were repeatedly studied in detail. Data on Jurassic flora of the Basin are cited in various works [14–16, 22, 27, 29]. The results of the studies on some groups of fossil plants are published in several papers [4–6, 8–12, 18–20, 25]. Despite the large number of publications, there is no unified view on stratigraphy of Jurassic sediments of the Irkutsk Basin. Against the background of well-studied Jurassic floras of the Kuznetsk [17], the Kansk Basins [24], and Western Siberia [21], Jurassic flora is still poorly studied. Paleobotanical characteristic of formations needs clarification, and stratigraphic importance of some species of fossil plants requires revision. For example, species *Phlebopteris polypodioides* Brongn and *Clathropteris obovata* Oishi indicated in regional stratigraphic scheme [2] are rare, and some representatives of genus *Coniopteris* are abolished [*C. clavipes* (Heer) Pryn., *C. trautscholdii* (Heer) Pryn.] [18], consequently, they cannot be used in stratigraphy.

The aim of this work is to suggest a solution for the above-listed problems by the implementation of comprehensive lithologic and paleobotanical study of key sections of Jurassic sediments within present-day active coal deposits rich in paleobotanical material.

2. Methods

Starting in 2008 and in 2016, the authors carried out quite a number of field works in order to explore lithologic and paleobotanical peculiarities in all active coal deposits within the Irkutsk Basin (see **Figure 1**). Opencasts of three coal-producing quarries: Cheremkhovo, Mugun, and Glinki were studied in detail. In addition, 13 exposures which are stratotypes of regional stratigraphic units were studied. The leaves of Ginkgoales and Leptostrobales were investigated by the epidermal-cuticular method. Leaf cuticles were macerated by the standard technique in Schultze mixture. Microslides were examined using the Olympus BX41TF light microscope and electronic scanning microscope Philips' SEM 525-M. About one hundred pieces of ore and more than 300 microslides with unfolded pattern of leaves' compressions were studied.

3. Lithostratigraphy of the formations of the Irkutsk Basin

The Cheremkhovskaya Formation was first identified by Korovin [23] in mines within the Cheremkhovo settlement vicinity. It represents a complete megarhythm and is divided into three subformations: lower, middle, and upper ones with total thickness up to 380 m.

Lower Cheremkhovskaya (Zalarinskaya) Subformation occurs with discordance on Cambrian limestones of Angarskaya Group. The subformation base is composed of clastic

deposits—conglomerates, gravelites, and coarse-grained sandstones which are overlapped by siltstones, mudstones with thin coal bands.

On the right bank of the Zalari river, on the opposite side of the Zalari settlement is situated the stratotype of Lower Cheremkhovskaya Subformation (bottom-up):

		Thickness, m
1.	Conglomerates interstratifying with coarse-grained sandstones	0.65
2.	Sandstones, coarse-grained, massive	1.34
3.	Conglomerates, fine-pebbled	2.00
4.	Sandstones, white, coarse-grained, massive	0.30
5.	Conglomerates, fine-pebbled	0.80
Disappearance of outcrop		3.00
6.	Sandstones, gray, medium-fine-grained with horizontal bedding and abundant plant detrital matter	0.70
Disappearance of outcrop		3.50
7.	Sandstones, pale gray, coarse-grained, massive	0.60
8.	Sandstones, gray, medium-grained with horizontal bedding	0.60
Disappearance of outcrop		1.39
9.	Sandstones, red, medium-fine-grained with horizontal bedding	1.10
10.	Alternation of red, burnt rocks presented by sandstones and siltstones with horizontal bedding and impressions of *Cladophlebis haiburnensis* (L. et H.) Sew., *Sphenobaiera ex gr. czekanowskiana* (Heer) Flor., *Czekanowskia ex gr. rigida* Heer, *Podozamites eichwaldii* Pryn. var. *minor* Pryn. *Ixostrobus grandis* Tesl.	3.54
11.	Speckled sandstones, coarse-medium-grained with horizontal bedding	0.75
Developed thickness		13.12

Clastic deposits of the lower subformation are traced by us in some natural outcrops along the ranks of the Bol'shaya Belaya river.

Industrially coal-bearing **Middle Cheremkhovskaya Subformation** is a natural sedimentary continuation of the lower subformation, and it is related to the latter by gradual transitions. This subformation is characterized by abundance in section of siltstones, mudstones, and coal seams with thickness up to 10–15 m. The thickness was cumulated during the epoch of maximum regional coal storage within the Basin and is abundant all over. Lower boundary line is drawn in bottom of siltstones and sandstones underlying the first coal-bearing horizon.

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		Thickness, m
Middle Cheremkhovskaya Subformation		
1.	Siltstones, gray	0.60
2.	Coal hard	0.50
3.	Mudstones, coaly with horizontal bedding	0.20
4.	Coal	0.30
5.	Mudstones, coaly with horizontal bedding	0.20
6.	Coal	0.50
7.	Mudstones, coaly with horizontal bedding	0.25
8.	Coal	0.80
9.	Sandstones, gray, medium-fine-grained with horizontal bedding, contain plant remains of *Czekanowskia* ex gr. *rigida* Heer	1.00
10.	Siltstones, gray	0.40
11.	Sandstones, gray, medium-fine-grained	1.45
12.	Siltstones, gray, with horizontal bedding	0.30
13.	Sandstones, gray, medium-fine-grained	0.50
14.	Mudstones, coaly, with horizontal bedding	0.20
15.	Sandstones, gray, fine-grained with horizontal bedding	2.00
16.	Siltstones, gray, with horizontal bedding, contain plant remains of *Equisetites lateralis* (Phill) Phill., *Cladophlebis haiburnensis* (L. et H.) Sew., *Cl. williamsonii* Brongn., *Raphaelia diamensis* Sew., *Sphenobaiera czekanowskiana* (Heer) Flor., *S. vigentis* Kiritch. et Bat., *Pseudotorellia paradoxa* Dolud., *Czekanowskia rigida* Heer, *Cz. baikalica* Kiritch. et Samyl., *Pityophyllum ex gr. nordenskioldii* (Heer) Nath., *Carpolithes cinctus* Nath., *Ixostrobus heeri* Pryn., and *Ix. grandis* Tesl.	1.20
17.	Coal	1.00
18.	Mudstones, coaly with horizontal bedding, contain fossil plant remains of *Cladophlebis* sp., *Czekanowskia baikalica* Kiritch. et Samyl., and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath	0.20
19.	Coal	0.78
20.	Mudstones, coaly with horizontal bedding	0.10
21.	Coal	0.45
22.	Mudstones, coaly with horizontal bedding	0.14
23.	Coal	0.40
24.	Siltstones, gray, rich in plant remains of *Lycopodites sp., Czekanowskia* ex gr. *rigida* Heer, *Phoenicopsis* ex gr. *angustifolia* Heer, *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., and *Schizolepis follinii* Nath.	0.64
25.	Coal	0.20

		Thickness, m
26.	Siltstones, gray, with burst plant detritus	0.30
27.	Sandstones, yellow, medium-fine-grained with impressions of *Czekanowskia* ex gr. *rigida* Heer and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath.	2.00
28.	Coal	0.20
29.	Sandstones, yellowish-gray, coarse-grained	1.65
30.	Sandstones, gray, medium-fine-grained with leaf impressions of *Czekanowskia* ex gr. *rigida* Heer and coalified plant detritus	0.80
31.	Coal	0.20
32.	Sandstones, yellowish-gray, medium-fine-grained, poorly cemented, flat-bedded with abundant plant detritus	0.80
33.	Coal	0.20
Upper Cheremkhovskaya Subformation		
34.	Sandstones, yellow, medium-grained	4.50
35.	Conglomerates, fine-pebbly	0.30
36.	Sandstones, yellow, medium-grained polymictic	4.60
Thickness of the opencast developed part		29.47

Section uncovering within the Cheremkhovo coal deposit situated in the central part of the Irkutsk Basin is a stratotype of Middle Cheremkhovskaya Subformation (bottom-up) (**Figure 2**):

Middle Cheremkhovskaya Subformation is opened in coal opencasts of the Glinki and Mugun deposits. The Glinki coal-bearing deposits occur on erosional contacts with a weathered surface of the Upper Cambrian clays (**Figure 2**). Opened thickness of Jurassic deposits is 18.4 m. Middle Cheremkhovskaya Subformation composed of gray, flat bedded, fine-grained sandstones, siltstones, and mudstones with two coal seams of industrial thickness (2–5.8 m) is exposed in the lower part of the opencast. We revealed the following plant remains: *Equisetites asiaticus* Pryn., *Equisetites* cf. *lateralis* (Phill.) Phill., *Hausmannia crenata* (Nath.) Maell., *Cladophlebis williamsonii* Brongn., *Cl. haiburnensis* (L et H) Sew., *Ginkgo concinna* Heer, *Sphenobaiera czekanowskiana* (Heer) Florin, *Pseudotorellia* cf. *paradoxa* Dolud., *Czekanowskia baikalica* Kiritch. et Samyl., *Cz. rigida* Heer, *Phoenicopsis* ex gr. *angustifolia* Heer, *Leptostrobus laxiflora* Heer, *Podozamites* cf. *lanceolatus* (L. et H.) Schimp., *P.* cf. *eichwaldii* Pryn. var. *major* Pryn., *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., *Schizolepis* cf. *moelleri* Sew., *Carpolithes minor* Pryn., and *Ixostrobus heeri* Pryn. in siltstones and mudstones of industrially coal-bearing part of the opencast.

The Mugun lignite deposit is situated in the northwestern part of the Irkutsk Basin, at 40 km to the south of the Tulun city. The deposit has an irregular shape and a simple geological structure. Lower band of the deposit belongs to Middle Cheremkhovskaya Subformation. It is composed of siltstones, mudstones, and fine-grained sandstones alternating among themselves. Productive coal seams (thickness from 3.5 up to 10 m) are confined to this part of

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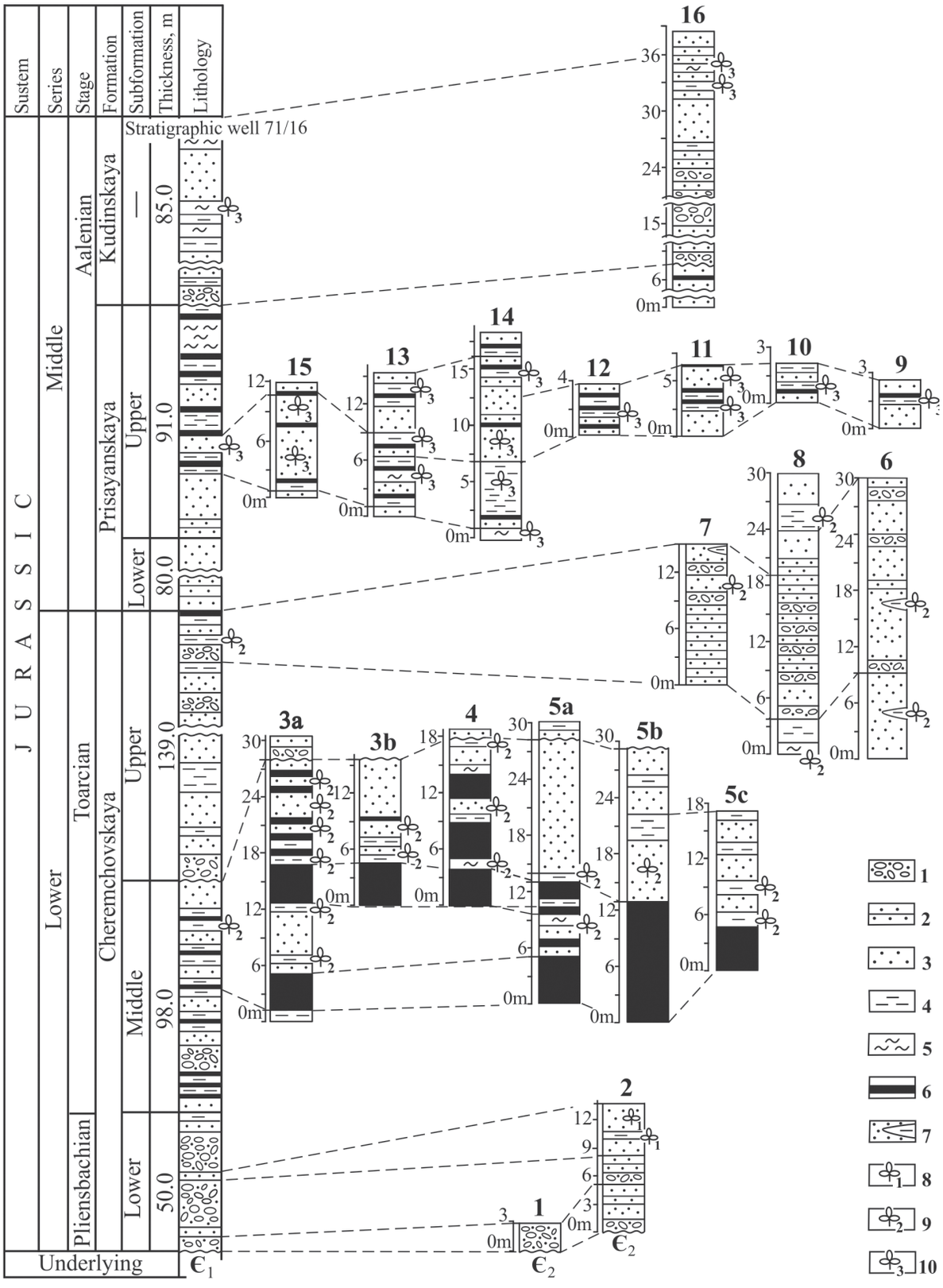

Figure 2. Correlation scheme of the key sections of Jurassic sediments of the Irkusk Basin. Numbering of sections is given in **Figure 1**. 1—conglomerates, 2—coarse-grained sandstones, 3—medium- and fine-grained sandstones, 4—siltstones, 5—mudstones, 6—coals, 7—lenses; plant remains: 8—with no stratigraphic importance, 9—typical of Cheremkhovo plant assemblage, 10—typical of Prisayan plant assemblage.

opencast. We distinguished the following plant remains: *Coniopteris* sp., *Lobifolia nana* A. Frol., *Czekanowskia rigida* Heer, *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., and *Carpolithes heeri* Tur.-Ket. [10] in siltstones and mudstones of this band.

Upper Cheremkhovskaya (Ust'-Baleiskaya) Subformation overlaps in concordance with the Middle Cheremkhovskaya Subformation, and more than a half of the former is composed of fine- and medium-grained sandstones with lenses of siltstones and mudstones. Lower boundary line is drawn in the bottom of sandstones of channel facies [1] and it is observed within opencasts of developed coal deposits (Cheremkhovo, Glinki, and Mugun; **Figure 2**). Outcrop situated at 2.1 km below the Ust'-Baley settlement is a stratotype of the upper subformation. Gray, differently grained polymictic sandstones with horizontal cross, uni-, and diversidirectional lamination dominate in its lower part. Sandstones contain two lenses composed of siltstones and mudstones with horizontal and sometimes banded lamination. Lower lens is long about 70 m with thickness up to 2 m. Impressions of the following plants: *Lycopodites tenerrimus* Heer, *Czekanowskia rigida* Heer, *Elatides ovalis* Heer, *Ixostrobus* sp., *Carpolithes deplanatus* Pryn., *C. cinctus* Nath., and *Samaropsis rotundata* Heer are found on the surface of mudstone bedding.

Thickness of the upper lens reaches 5.8 m, and its length is about 120 m. Siltstones and mudstones of the lens contain numerous impressions of insects and fewer those of fishes and shells of limnetic myarians. Plant remains of *Lycopodites tenerrimus* Heer, *L. trichiatus* Pryn. emend. A. Frol. et Mash., *Phyllotheca sibirica* Heer, *Coniopteris murrayana* (Brongn.) Brongn., *Sphenobaiera czekanowskiana* (Heer) Florin, *Czekanowskia rigida* Heer, *Leptostrobus laxiflora* Heer, *Elatides ovalis* Heer, *Ixostrobus heeri* Pryn., and *Samaropsis rotundata* Heer are found on several plates of beddings.

Outcrops situated on the opposite side of the Tel'ma settlement (**Figure 2**) and the Tolstyi Cape have similar lithologic structure. The following plant remains: *Cladophlebis* cf. *haiburnensis* (L. et H.) Sew., *Cl. williamsonii* Brongn., *Sphenobaiera czekanowskiana* (Heer) Flor., *S. vigentis* Kiritch. et Bat., *Pseudotorellia longifolia* Dolud., *Czekanowskia rigida* Heer, *Cz. baikalica* Kiritch. et Samyl., *Leptostrobus laxiflora* Heer, *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., *Schizolepis* sp., *Samaropsis rotundata* Heer, and *Carpolithes* cf. *minor* Pryn. are revealed in siltstone lens opened by these outcrops.

Prisayanskaya Formation is less abundant relative to the Cheremkhovskaya one which is overlapped with conformability by it.

Lower Prisayanskaya (Idanskaya) Subformation is predominantly confined to the southeastern part of the Basin, its thickness is of 50–70 m. Characteristic feature of its sections is the prevalence of coarse-grained and gritty sandstones as well as siltstones containing indeterminable plant remains of poor preservation. Conglomerates and gritstones occur on several areas in the base of subformation. Lower boundary line of subformation is drawn relative to band bottom of rhythmically alternating sandstones, gritstones, conglomerates, and siltstones. It is sufficiently conventional.

Upper Prisayanskaya (Sukhovskaya) Subformation is preserved from erosion only in Priirkut depression. This subformation is composed of small and fine-grained sandstones and siltstones, and coarse-grained varieties of sandstones are rare. The characteristic feature of this subformation

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is the significant enrichment of rocks in coaly matter and the presence of coal bands. Thickness of this subformation is about 50 m. Its lower boundary with the lower subformation is not always distinct. Within Priirkut depression we studied outcrops of this Upper Prisayanskaya Subformation situated along the banks of the Angara, Irkur, Kaya, and Topka rivers.

In the quarry situated on Kaiskaya Gora at 400 m above the Kaya river mouth in the Irkutsk city the Jurassic deposits of Upper Prisayanskaya Subformation are opened (bottom-up).

		Thickness, m
1.	Sandstones, yellowish-gray, fine- and medium-grained, contain plant remains of *Cladophlebis williamsonii* Brongn., *Phoenicopsis angustifolia* Heer, and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath.	2.00
2.	Siltstones and silty sandstones, yellowish-gray, with impressions of plants: *Lobifolia lobifolia* (Phill.) Rasskaz. et E. Leb., *Coniopteris maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *Cladophlebis williamsonii* Brongn., *Czekanowskia* ex gr. *rigida* Heer, *Phoenicopsis angustifolia* Heer, *Ph. Markovitchiae* Kiritch. et Schischk., *Ph. dentata* Pryn., Ph. irkutensis Dolud. et Rasskaz., and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath.	0.20
3.	Coal	0.40
4.	Sandstones, yellowish-gray, fine-grained, contain plant impressions of *Coniopteris maakiana* (Heer) Pryn. emend. Kiritch. et Trav., C. cf. *sachsii* Tesl.	0.20
Opened thickness		2.80

The section of Upper Prisayanskaya Subformation is opened within Sinyushina Gora in the Irkutsk city. Gray, fine- and medium-grained sandstones dominate in the lower part of the section. The section's upper part is composed of alternating medium-grained sandstones and siltstones, only one thin (0.07 m) coal band is noted. *Coniopteris murrayana* (Brongn.) Brongn., *Cladophlebis nebbensis* (Brongn.) Nath., *Cl. williamsonii* Brongn., *Czekanowskia* ex gr. *rigida* Heer, *Phoenicopsis angustifolia* Heer, *Ph. samylinae* Kiritch. et Moskv., *Ph. irkutensis* Dolud. et Rasskaz., and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath are revealed among plant remains.

The upper part of Upper Prisayanskaya Subformation of 5.4 m thickness and 400 m length is opened in roadside quarry near the Smolenshchina settlement. The section is of rhythmic structure. In this section, quartz-feldspathic coarse- and medium-grained sandstones alternate upward with fine-grained sandstones, siltstones, and mudstones with thin (0.1–0.3 m) coal bands. *Hepaticites arcuatus* (L. et H.) Harris, *Coniopteris murrayana* (Brongn.) Brongn., *C. maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *C. spectabilis* Brick, *Cladophlebis williamsonii* Brongn., *Cl. haiburnensis* (L. et H.) Brongn., *Cl.* cf. *nebbensis* (Brongn.) Nath., *Raphaelia diamensis* Sew., *Sphenobaiera* ex gr. *czekanowskiana* (Heer) Flor., *Ginkgo* ex gr. *sibirica* Heer, *Czekanowskia* ex gr. *rigida* Heer, *Phoenicopsis angustifolia* Heer, *Ph.* cf. *mogutchevae* Kiritch. et Trav., *Ph. cognata* Kiritch., *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., and *Stenorachis* (?) *clavata* Nath. are identified among plant remains.

One of the key sections of the Upper Prisayanskaya Subformation is outcrops situated on the left bank of the Irkutsk water reservoir on the opposite side of the Stroitel' settlement (**Figure 2**). The section has a rhythmic structure. Bases of rhythms are presented by quartz fieldspathic coarse- and medium-grained sandstones alternating upward the section with fine-grained sandstones, siltstones, and mudstones with thin (0.1–0.3 m) coal bands. Near water's edge are exposed the following rocks:

		Thickness, m
1.	Sandstones, gray medium-grained, horizontally bedded micaceous	0.14
2.	Sandstones, silty, gray, plant detritus is exposed, plant detritus is found in the upper part of the layer	0.46
3.	Hard coal	0.12
4.	Mudstones, gray	0.04
5.	Hard coal	0.16
6.	Mudstones, coaly, horizontally bedded with abundant plant detritus	0.13
7.	Hard coal	0.07
8.	Mudstones, coaly, horizontally bedded, contain abundant plant detritus of *Coniopteris maakiana* (Heer) Pryn. emend. Kirich. et Trav., *Cladophlebis* cf. *williamsonii* Brongn., *Raphaelia diamensis* Sew., *R. tapkensis* (Heer) Pryn. emend. Kost., *Czekanowskia* ex gr. *rigida* Heer, and *Phoenicopsis* ex gr. *angustifolia* Heer	0.11
9.	Sandstones, gray, medium-grained with plant detritus	0.07
10.	Sandstones, gray medium-grained with distinct cross bedding and impressions of trunks. Leaf mats of *Phoenicopsis* ex gr. *angustifolia* Heer are found at 0.4 m from the bottom layer	1.10
11.	Sandstones, gray, horizontally bedded with plant detritus	0.10
12.	Mudstones, gray, horizontally bedded. Impressions of *Coniopteris maakiana* (Heer) Pryn. emend. Kirich. et Trav., *Cladophlebis nebbensis* (Brongn.) Nath., *Cl. williamsonii* Brongn., *Cl. haiburnensisi* (L. et H.) Sew., *Raphaelia diamensis* Sew., *R. tapkensis* (Heer) Pryn. emend. Kost., *Sphenobaiera* ex gr. *czekanowskiana* (Heer) Florin, *Pseudotorellia* cf. *ensiformis* (Heer) Dolud., *P.* cf. *paradoxa* Dolud., *Czekanowskia* ex gr. *rigida* Heer, *Phoenicopsis angustifolia* Heer, *Elatocladus manchuricus* (Yok.) Yabe, and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath. are found in the lower part of the layer	0.10
13.	Sandstones, gray, medium-grained with cross bedding and plant detritus	0.90
14.	Hard coal	0.06
15.	Mudstones with plant remains, poorly preserved	0.03
16.	Coal	0.04
17.	Mudstones, gray, with impressions of fossil plant remains: *Coniopteris maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *C. murrayana* (Brongn.) Brongn., *Cladophlebis haiburnensis* (L. et H.) Sew., *Cl. williamsonii* Brongn., *Phoenicopsis* ex gr. *angustifolia* Heer, and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath.	0.55
18.	Sandstones, medium-grained, massive	0.60

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		Thickness, m
19.	Sandstones, horizontally bedded with impressions of *Lycopodites baicalensis* A. Frol., *Cladophlebis* cf. *nebbensis* (Brongn.) Nath., *Phoenicopsis* ex gr. *angustifolia* Heer, and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath.	0.25
20.	Coal	0.02
21.	Sandstones, gray, fine-grained with thin slab parting	0.23
22.	Sandstones, gray, coarse-grained, cross-bedded with trunks of trees	4.00
23.	Sandstones, gray, medium-grained with two coal bands (0.02 and 0.03 m)	0.35
24.	Siltstones, gray, with plant remains: *Cladophlebis nebbensis* (Brongn.) Nath., *Cl. haiburnensis* (L. et H.) Sew., *Cl. williamsonii* Brongn., *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., *Carpolithes cinctus* Nath.	0.10
25.	Sandstones, gray, fine-grained, cross-bedded, with impressions of *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., poorly preserved	2.00
26.	Mudstones, coaly, with coal band (0.03 m)	0.23
27.	Mudstones, gray, with impressions of ancient plants: *Lycopodites baikalensis* A. Frol., *Hausmannia crenata* (Nath.) Maell., *Raphaelia* cf. *tapkensis* (Heer) Pryn. emend. Kost., *Czekanowskia* ex gr. *rigida* Heer, *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., and *Carpolithes heeri* Tur.-Ket.	0.15
28.	Sandstones, medium-grained, horizontally bedded	1.70
Thickness of the section opened part		13.21

The Upper Prisayanskaya Subformation outcrop within the Topka creek valley is presented by 18-meter-thick section having a rhythmic structure (**Figure 2**). The bases of rhythms are composed of quartz fieldspathic coarse- and medium-grained sandstones, siltstones, and mudstones with thin (0.1–0.3 m) coal bands. *Coniopteris murrayana* (Brongn.) Brongn., *C. maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *Cladophlebis williamsonii* Brongn., *Cl. haiburnensis* (L. et H.) Sew., *Czekanowskia* ex gr. *rigida* Heer, *Phoenicopsis* ex gr. *angustifolia* Heer, *Phoenicopsis* ex gr. *speciosa* Heer, and *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath. are revealed among plant remains.

The Upper Prisayanskaya Subformation is exposed on the left bank of the Irkut river, 1.5 km below the Pionersk settlement (**Figure 2**). Outcrop of 800 m length has a rhythmic structure. The rhythm bases are composed of quartz fieldspathic coarse- and medium-grained sandstones (3–4 m) alternating upward with siltstones and mudstones with thin (0.1–0.2 m) coal bands. The following plant remains of *Coniopteris maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *C.* cf. *spectabilis* Brick, *Coniopteris* sp., *Cladophlebis williamsonii* Brongn., *Cl. williamsonii* Brongn. var. *punctata* Brick, *Cl. nebbensis* (Brongn.) Nath., *Raphaelia diamensis* Sew., *Raphaelia tapkensis* (Heer) Pryn. emend. Kost., *Ginkgo* ex gr. *sibirica* Heer, *Sphenobaiera* ex gr. *czekanowskiana* (Heer) Flor., *Czekanowskia* ex gr. *rigida* Heer, *Phoenicopsis angustifolia* Heer, *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., *Ixostrobus heeri* Pryn., *Carpolithes deplanatus* Pryn., and *Stenorhachis* sp. are identified in siltstones and fine-grained sandstones.

The Kudinskaya Formation is located in the northeast of the Irkutsk city within the Kuda trough, overlaps discordantly with the Prisayanskaya Formation. The formation is charac-

terized by rubbly pebbled conglomerates and coarse-grained sandstones, thin interlayers of siltstones and mudstones are rare. Thickness of the formation is 50–80 m. Identifiable remains of plants from the Kudinskaya Formation have been long unknown. In 2014 we studied the stratotype of Kudinskaya Formation which is located at 2 km to the north of the Zherdovka village. Clastic rocks opened within these outcrops contain thin interlayers of siltstones and mudstones. The following fossil plants: *Equisetites* sp., *Coniopteris maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *Czekanowskia curta* Kiritch. et Samyl., *Czekanowskia rigida* Heer, *Leptostrobus laxiflora* Heer, *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath. *Carpolithes cinctus* Nath., and *C. minor* Pryn. are found in mudstones [13, 26].

4. Discussion

The stratigraphic scale developed for Jurassic sediments of Western Siberia has been followed in the comparison of Jurassic sediments of the Irkutsk Basin with the adjacent regions of Western Siberia [3]. This scheme is comprehensively reasonable and can be considered as a comparative standard for large stratigraphic correlations and age dating of continental sections within Siberia.

Summarizing paleobotanical review of the aforementioned sections, it should be noted that plant assemblage identified in Lower Cheremkhovskaya Subformation is characterized by uncommon ferns *Cladophlebis haiburnensis* (L. et H.) Sew. and conifers *Podozamites eichwaldii* Pryn. var. *minor* Pryn., *Schizolepis* sp. Ginkgoales and Leptostrobales are presented by species *Sphenobaiera* ex gr. *czekanowskiana* (Heer) Flor. and *Czekanowskia* ex gr. *rigida* Heer, the latter one dominates among them. The taxonomic composition of the flora of the lower part of the Lower Cheremkhovskaya Subformation is comparable with Jagel'nyi fossil plant assemblage from the Lower Jurassic sediments of Western Siberia [21] (**Table 2**). The age of the Lower Cheremkhovskaya Subformation is determined within the framework of the second half of the Early Jurassic (Pliensbachian).

Various representatives of genus *Equisetites*: *E. lateralis* (Phill.) Phill. and *E. asiaticus* Pryn. are revealed in all studied sections of Middle and Upper Cheremkhovskaya Subformations. Genus *Cladophlebis* is presented by species *C. williamsonii* Brongn. and *Cl. haiburnensis* (L. et H.) Sew. that are abundant. *Czekanowskia rigida* Heer, *Cz. baikalica* Kiritch., *Sphenobaiera czekanowskiana* (Heer) Flor., *S. vigentis* Kiritch. et Bat., *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath. Реже встречаются *Lycopodites* sp., *Lobifolia nana* A. Frol., *Ginkgo* ex gr. *sibirica* Heer, *Pseudotorellia paradoxa* Dolud., *Phoenicopsis* ex gr. *angustifolia* Heer, *Leptostrobus laxiflorus* Heer, *Elatocladus manchuricus* (Yok.) Uabe, *Carpolithes cinctus* Nath., *C. minor* Pryn., *Carpolithes* sp., *Ixostrobus heeri* Pryn., *Ix. grandis* Tesl., and *Schizolepis follinii* Nath. play the role of cosmopolites among gymnosperms. *Hausmannia crenata* (Nath.) Maell., *Raphaelia diamensis* Sew., *Ginkgo concinna* (Heer) Sew., *Podozamites* cf. *lanceolatus* (L. et H.) Schimp., and *P.* cf. *eichwaldii* Pryn. var. *major* Pryn. are presented by several finds.

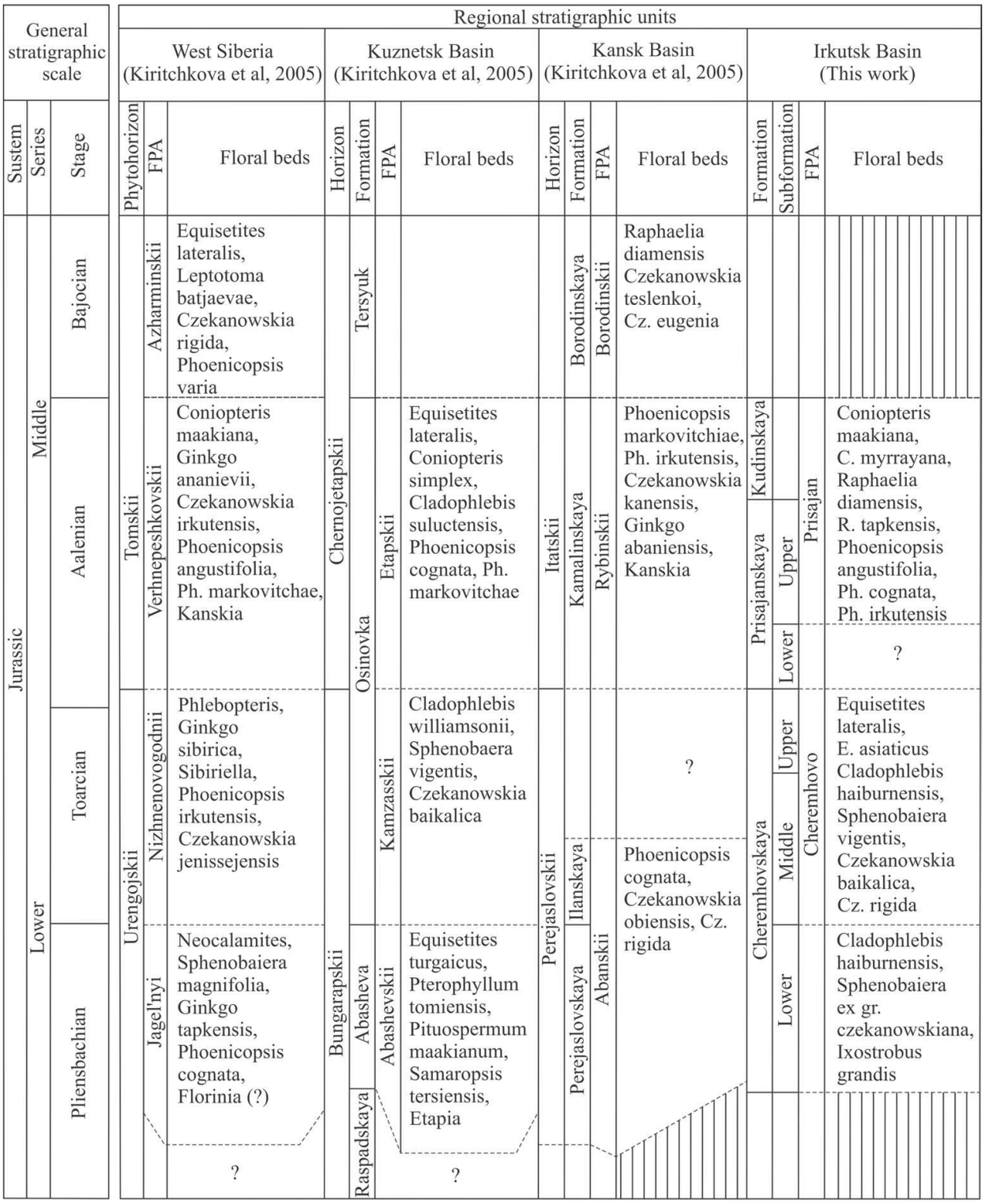
In whole, the flora composition of Middle and Upper Cheremkhovskaya Subformations is very consistent in outcrops that allow us to consider it as Cheremkhovo fossil plant assemblage

[7]. *Equisetites lateralis* (Phill.) Phill., *E. asiaticus* Pryn., *Cladophlebis haiburnensis* (L. et H.) Sew., *Sphenobaiera czekanowskiana* (Heer) Flor., *S. vigentis* Kiritch. et Bat., *Czekanowskia baikalica* Kiritch. et Samyl., and *Cz. rigida* Heer whose remains dominate in the sections of Cheremkhovskaya Formation are typical of the assemblage (**Table 1**). Section of Middle

Fossil plant assemblage	Fossil plants \ Locations	Cheremchovskaya Formation						Prisayanskaya Formation							Kudinskaya Formation
		Middle Subformation			Upper Subformation										
		3	4	5	6	7	8	9	10	11	12	13	14	15	16
Prisayan	*Lycopodites baikalensis*											+			
	Lycopodites subulifolius										+				
	Coniopteris maakiana							□		□	□	□	□	□	□
	Coniopteris murrayana				+				□	□	□	□	□		
	Coniopteris spectabilis									+				+	
	Coniopteris cf. *sachsii*							+							
	Cladophlebis williamsonii	+	+				+	□	□	□	□	□	□	□	
	Cladophlebis nebbensis								□	+	□	□		□	
	Cladophlebis kanskiensis											+			
	Raphaelia diamensis	+								□	□	□		□	
	Raphaelia tapkensis										+	+		+	
	Baiera majaea									+					
	Ginkgo tapkensis									□					
	Phoenicopsis angustifolia							□	□	□	□	□	□	□	
	Phoenicopsis samylinae								□			□			
	Phoenicopsis dentata							+							
	Phoenicopsis irkutensis							□	□			□			
	Phoenicopsis markovitchiae							+							
Cheremchovo	*Lycopodites tenerrimus*				+										
	Lycopodites trichiatus				+										
	Equisetites lateralis	□	□												
	Equisetites asiaticus	□	□												
	Lobifolia nana			+						+		+	+		
	Cladophlebis haiburnensis	□	□				+			+		+		+	
	Sphenobaiera czekanowskiana	□	□		□	□	□								
	Sphenobaiera vigentis	□				□	□								
	Czekanowskia baikalika	□	□	□		□	□				+			+	
	Czekanowskia rigida	□	□	□	□	□	□								

Note: Numbering of fossil plan occurrences is given in **Figure 1**. □—Species dominates in burials, +—species is present in burials.

Table 1. Taxonomic composition and stratigraphic distribution of fossil plant assemblages within Jurassic sediments of the Irkutsk Basin.



Note: FPA—Fossil plant assemblage.

Table 2. Correlation scheme of Jurassic sediments of the Irkutsk Basin and adjacent areas on paleobotanical data.

Cheremkhovskaya Subformation of the Cheremkhovo hard coal deposit is a key for layers of the assemblage. Degree of development of the Cheremkhovo assemblage floras is comparable with floras of Novogodnii (Western Siberia) and Kamzasskii (Kuznetsk Basin) assemblages

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(**Table 2**). Thus, the age of Middle and Upper Cheremkhovskaya Subformations is determined in the range of Toarcian.

The performed paleobotanical analysis of fossil plants found within Prisayanskaya and Kudinskaya Formations suggests that the time of their accumulation concurred with the flourishing of ferns of the genera *Conipteris* (*C. maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *C. murrayana* (Brongn.) Brongn., *C. spectabilis* Brick, *C.* cf. *sachsii* Tesl.), *Cladophlebis* (*Cl. argutula* (Heer) Font., *Cl. haiburnensis* (L. et H.) Brongn., *Cl. kanskiensis* Kost., *Cl. nebbensis* (Brongn.) Nath., and *Cl. williamsonii* Brongn.) and *Raphaelia* (*R. diamensis* Sew. and *R. tapkensisi* (Heer) Pryn. emend Kost.). *Coniopteris maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *Raphaelia diamensis* Sew., and *Cladophlebis nebbensis* (Brongn.) Nath. are dominant among them. *Coniopteris murrayana* (Brongn.) Brongn. *и Raphaelia tapkensis* (Heer) Pryn. emend Kost. occur rarely. Genus *Phoenicopsis,* presented by six species: *Ph. angustifolia* Heer, *Ph. samylinae* Kiritch. et Moskv., *Ph. irkutensis* Dolud. et Rasskaz., *Ph. cognata* Kiritch., *Ph. dentata* Pryn., and *Ph. markovitchiae* Kiritch. et Schischk. presented in majority of occurrences, is the most diverse among gymnosperms (**Table 1**). *Czekanowskia* genus is presented by species *Czekanowskia curta* Kiritch. et Samyl, *Cz. irkutensis* Kiritch. et Samyl, and *Cz. rigida* Heer. *Ginkgo* ex gr. *sibirica* Heer. and *G. tapkensis* Dolud. et Rasskaz. are frequent. Besides them, *Hepaticites arcuatus* (L. et H.) Harris, *Lycopodites baikalensis* A. Frol., *L. subulifolius* A. Frol. et Mash., *Phyllotheca sibirica* Heer, *Hausmannia crenata* (Nath.) Mael., *Lobifolia lobifolia* (Phill.) Rasskaz. et E. Leb., *Anomozamites lindleyanus* Schimp., *Sphenobaiera* ex gr. *czekanowskiana* (Heer) Florin, *Pseudotorellia* cf. *ensiformis* (Heer) Dolud., *P.* cf. *paradoxa* Dolud., *Taxocladus ketovae* Tesl., *Elatocladus manchuricus* (Yok.) Yabe, *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., *Ixostrobus heeri* Pryn., *Carpolithes cinctus* Nath., *C. deplanatus* Pryn., *C. heeri* Tur.-Ket., *C. minor* Pryn., *Schizolepis follinii* Nath., *Samaropsis rotundata* Heer, and *Stenorachis* (?) *clavata* Nath. are found within the Prisayanskaya Formation.

The flora composition of Prisayanskaya and Kudinskaya Formations shows good horizontal consistency, and we consider it as Prisayan fossil plant assemblage. Species *Coniopteris maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *C. murrayana* (Brongn.) Brongn., *C. spectabilis* Brick., *Cladophlebis nebbensis* (Brongn.) Nath., *Raphaelia diamensis* Sew., *R. tapkensis* (Heer) Pryn. emend Kost., *Phoenicopsis angustifolia* Heer, *Ph. cognata* Kiritch., and *Ph. irkutensis* Dolud. et Rasskaz., the remains of which prevail in the sections of Prisayanskaya and Kudinskaya Formations (**Table 1**), are characteristic of this assemblage [7, 13]. Composition of Prisayan assemblage allows it to compare to Verkhnepeshkovskii (Western Siberia), Rybinskii (Kansk Basin) and Etapskii (Kuznetsk Basin) fossil plant assemblages and date including sediments to the beginning of Middle Jurassic (Aalenian) (**Table 2**). Outcrops situated near the Smolenshchina settlement and on the left bank of the Irkutsk water reservoir serve as key sections for Prisayan assemblage.

Plant remains from the sections of Upper Prisayanskaya Subformation opened within the Topka river were previously compared, according to the level of flora development, with Azharminskii fossil plant assemblage traced in Tyumen'skaya Formation of Ob'-Tazovskaya area of Western Siberia [21]. Azharminskii assemblage is characterized by renewal of species composition of genera *Coniopteris*, *Czekanowskia*, and *Phoenicopsis*. Genus *Coniopteris* is replenished with species *C. burejensis* (Zaless.) Sew., *C. (Birissia?) depensis*

E. Leb. Species *C. hymenophylloides* (Brongn.) Sew., *C. simplex* (L. et H.) Harris, *C. vsevolodii* E. Leb. Occur everywhere. Genus *Phoenicopsis*, presented by 10 species, is the most diverse among Leptostobales. Species *Ph. taschkessiensis* Krasser and *Ph. mogutchevae* Kiritch. et Trav. are the first to occur among them. The most abundant are species *Ph. samylinae* Kiritch. et Moskvin., *Ph. sibirica* Kiritch. et Trav., and *Ph. varia* Kiritch. et Trav. The age of sediments including Azharminskii fossil plant assemblage is determined in the range of Bajocian stage. Analysis of flora taxonomic composition from the sections of the Topka river revealed in it the lack of all new species of genera *Coniopteris* and *Phoenicopsis* typical of Azharminskii assemblage (**Table 1**). Thus, according to the available data, there is no Bajocian flora within the Irkusk Basin.

5. Conclusion

The results of lithologic and paleobotanical investigations of Lower and Middle Jurassic sediments of the Irkutsk Basin allowed to draw the following conclusions.

Two uneven-aged fossil plant assemblages: Cheremkhovo for the Middle and Upper Cheremkhovskaya Subformations and Prisayan for the Prisayanskaya and Kudinskaya Formations were identified.

Species *Equisetites lateralis* (Phill.) Phill., *E. asiaticus* Pryn., *Cladophlebis haiburnensis* (L. et H.) Sew., *Sphenobaiera czekanowskiana* (Heer) Flor., *S. vigentis* Kiritch. et Bat., *Czekanowskia baikalica* Kiritch. et Samyl., and *Cz. rigida* Heer were dominated in sections of Middle and Upper Cheremkhovskaya Subformations. Level of development of Cheremkhovo assemblage is comparable with flora of Nizhnenovogodnii (Western Siberia) and Kamzasskii (Kuznetsk Basin) assemblages. Therefore, the age of Middle and Upper Cheremkhovskaya Subformations including Cheremkhovo assemblage is determined by the end of Early Jurassic (conventionally, Toarcian).

Species *Coniopteris maakiana* (Heer) Pryn. emend. Kiritch. et Trav., *C. murrayana* (Brongn.) Brongn., *C. spectabilis* Brick., *Cladophlebis nebbensis* (Brongn.) Nath., *Raphaelia diamensis* Sew., *R. tapkensis* (Heer) Pryn. emend Kost., *Phoenicopsis angustifolia* Heer, *Ph. cognata* Kiritch., and *Ph. irkutensis* Dolud. et Rasskaz. are typical of Prisayan assemblage. The identified species composition of the Prisayan assemblage allowed to compare it with Verkhnepeshkovskii (Western Siberia), Rybinskii (Kansk Basin), and Etapskii (Kuznetsk Basin) fossil plant assemblages and to establish the formation age at the beginning of the Middle Jurassic (Aalenian).

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